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Grazing Influences on Mass, Nutritive Value, and Persistence of Stockpiled Jesup Tall Fescue without and with Novel and Wild-Type Fungal Endophytes

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ABSTRACT

Introducing novel endophytes into tall fescue (*Festuca arundinacea* Schreb.) that produce no ergot alkaloids could prevent negative impacts on animal performance while improving plant persistence. This 3-yr study evaluated 'Jesup' tall fescue (TF) for forage mass, nutritive value, and stand persistence when containing no endophyte, a novel endophyte (no ergot alkaloids), or a wild-type endophyte (ergot alkaloids). Forage was accumulated from mid-August and treatments consisted of (i) a grazed control (grazed when growth approximated 10 to 15 cm), or forage accumulated and grazed in (ii) mid-November, (iii) mid-December, (iv) mid-January, and (v) mid-February. Endophyte status had no influence on total forage mass; forage removed by grazing; proportion of leaf, stem, and dead fractions; or on nutritive value (except ergovaline which was greatest in the wild type). Delaying defoliation linearly reduced forage mass, ergovaline concentration, and nutritive value. All stands of TF declined with losses similar (P = 0.37) for wild-type and novel stands (29 vs. 42%) but were greatest for the TF without an endophyte (29 vs. 75%; P = 0.01 and 42 vs. 75%; P = 0.04). These data support the use of novel endophytes in TF for animal production and caution against the use of endophyte-free TF because of decreased stand longevity. The presence of ergovaline can be minimized by stockpiling TF with utilization after late autumn but occurs with a sacrifice in forage mass and nutritive value.

Tall fescue is a valuable forage grass in the USA predominating throughout a broad north–south transition zone (Burns and Chamblee, 1979). This is a result of its persistence in a region that is characterized by stress from hot summer temperatures, fluctuating winter climatic conditions (Templeton et al., 1961; Wolf, 1973; Buckner et al., 1979), and frequently adverse soil conditions (Cowan, 1956). Further, the nutritive value of tall fescue is generally comparable to other cool-season (C_3) grasses, such as orchardgrass (*Dactylis glomerata* L.) and bromegrass (*Bromus inermis* Leyss.) (Duell, 1960; Marten and Hovin, 1980; Prigge et al., 1999).

Animal responses from tall fescue, however, can be extremely variable because of the presence of an endophyte (*Neotyphodium coenophialum* Morgan-Jones and Gams.) that produces ergot alkaloids in the forage and can negatively influence the animal's physiological processes (Hill et al., 1994; Oliver, 1997). On the other hand, the presence of the endophyte has been associated with increased plant tolerance to environmental stress (Thompson et al., 2001) and pests (Funk et al., 1985; West et al., 1993). Loss of such plant attributes would reduce tall fescue's zone of adaptation.

Tall fescue is of particular value in ruminant production systems because autumn growth can be accumulated to provide a large quantity of pasture with high nutritive value for grazing throughout the late autumn and winter (Archer and Decker, 1977; Ocumpaugh and Matches, 1977; Fribourg and Bell, 1984; Burns and Chamblee, 2000). Recently, Jesup tall fescue has been released due to its greater tolerance to high summer temperatures and drought stress (Bouton et al., 1997). Presumably, this increases its adaptation and productivity farther south. Further, a novel (nontoxic) endophyte was incorporated into Jesup without the antiquality, ergot-alkaloid compounds (Bouton et al., 2002; Parish et al., 2003) and marketed under the trademark 'MaxQ' (Pennington Seed, Inc., Madison, GA). The objectives of this study were threefold. The first objective was to test the adaptation and production potential of Jesup tall fescue with the presence or absence of a novel (nontoxic) endophyte (MaxQ) for the mid-Atlantic region when subjected to two autumn managements of either repeated grazing or accumulated and grazed as an autumn stockpile. A second objective was to determine if the presence of a novel- or a wild-type endophyte would alter either the nutritive value of the forage or stand persistence when compared with the endophyte-free control. The final objective was to evaluate changes in grazed forage production and nutritive value of these forages during the autumn and winter when stockpiled for varying periods prior to grazing.

MATERIALS AND METHODS

General

The experiment was established on a Cecil clay loam (fine, kaolinitic, thermic Typic Kanhapludult) soil at the Reedy Creek Road Field Laboratory near Raleigh, NC, and conducted for 3 yr. The site was initially sprayed with glyphosate [*N*-(phosphonomethyl)glycine] in the spring and again in late summer, fertilized and limed according to soil test, deep disked, firmed by cultipacking, and seeded to Jesup tall fescue at 22 kg ha^{-1}. Planting occurred on 12 Oct. 1999 with a Truax sod drill (Truax Company, Inc., Minneapolis, MN). Planters were spaced 15 cm apart and coulters fitted with depth bands

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Abbreviations: ADF, acid detergent fiber; CP, crude protein; DDM, digestible dry matter; D/PS, di-and polysaccharides; HEMI, hemicellulose; IVTD, in vitro true dry matter disappearance; MS, monosaccharides; NDF, neutral detergent fiber; NIRS, near-infrared reflectance spectroscopy; TNC, total nonstructural carbohydrates.

set to place the seed at 1.3 to 1.9 cm deep. Excellent stands were obtained by the following spring.

The experiment was conducted in a split-plot design with three replicates. Three wholeplots, randomized within each replicate, were established to one of three seed lots of Jesup tall fescue with each wholeplot 73 by 26 m. One lot was free of endophyte, a second lot contained a novel, nontoxic endophyte (free of ergot alkaloids) marketed as MaxQ, and the third lot contained a wild-type endophyte capable of producing ergot alkaloids.

Within each wholeplot, five subplots (micropastures) 9.2 by 9.2 m, were randomly assigned to one of five grazing defoliation treatments. Defoliation treatments consisted of; (i) grazing autumn growth to about 7 cm each time it accumulated approximately 10 to 15 cm of forage; and grazing stockpiled forage on (ii) 15 November; (iii) 15 December; (iv) 15 January; and (v) 15 February. Animals on stockpiled forage were removed when forage was defoliated to approximately 7 to 10 cm.

Forage Management

The experiment was initiated the summer following the previous autumn's seeding with an accumulation starting date of 15 August. The stockpiled treatments were evaluated for 3 yr with stand counts taken the summer after completion (4 yr after seeding). Immediately prior to 15 August, all forage was removed to an 8-cm stubble and the area uniformly top dressed with 78 kg N ha^{-1} as ammonium nitrate. The subsequent stubble of pseudostem and leaf tissue became reduced close to the soil surface (<5 cm) during summer drought and the onset of stand dormancy.

Following the final defoliation date (15 February) the residual forage from all plots was removed each year with a flail harvester set to leave an 8-cm stubble. The experimental area was uniformly top dressed in early March with 78 kg N ha^{-1} and the initial spring forage permitted to grow to the early-boot stage. Thereafter, it was cut and removed as hay (April), the area was again top dressed with 78 kg N ha^{-1} (total of 234 kg N ha^{-1} for the year) and a second hay crop removed in late June to mid-July.

Plant Sampling

Endophyte Level

Fifty pseudostems were selected from each field in June prior to initiating the defoliation treatments from each wholeplot within each land replicate according to standard procedures (Randall-Schadel, 1995). Samples were tested by the NC Department of Agriculture's Service Laboratory for the presence of an endophyte. The degree of endophyte infestation averaged 94% for the wild-type endophyte stand, 95.3% for MaxQ stand, and 5.3% for the endophyte-free stand.

Stand Counts

Within each defoliation treatment (subplot) six estimates of stand density were obtained at initiation of the experiment (September 2000) and at termination of the experiment (October 2003). This was achieved by locating two fixed transects 4.6 m in length 1.8 m from each side of the subplot and a third transect in the center of the subplot. At a randomly selected position along each transect, two 1-m sections were used to estimate fescue stands resulting in six scores per subplot. At each 1-m observational site the presence and absence of tall fescue in each 25-mm increment was recorded. The six 1-m readings were averaged for each subplot resulting in an index expressed as a percentage of the stand that contained tall fescue in each subplot. At the end of the study the process was repeated for each fixed transect and the percentage of stand loss was estimated from the difference between initial and final stand indices with the result expressed as a percentage of the initial score. This value gives a sensitive index to changes in plant stand but is not equivalent to ground cover since the 25-mm sections were simply scored for presence or absence of fescue.

Forage Mass

Forage mass was determined pregrazing the afternoon prior to each grazing and postgrazing the day after grazing. The potential 0.51-m-wide harvest strips (without overlap) running the length of the subplot were enumerated. To avoid border effects the 0.51-m strip from each side of the subplot was removed from consideration. Each harvest strip was initiated and terminated 1.2 m from the ends of the subplot resulting in a 6.8 by 0.51 m harvest strip. The particular strip to be harvested pregrazing was selected at random within each subplot for each defoliation event. The forage was harvested with a 0.51-m wide rotary mower fitted with a collection bag to a 5-cm stubble. The fresh forage was weighed and a subsample obtained and dried in a forced-air oven (75°C) for 48 h to estimate dry matter concentration. After grazing each treatment, postgrazing forage mass to a 5-cm stubble was obtained from a second harvest strip to the immediate right (0.1 m) of the pregrazing forage mass strip. The fresh forage weight was multiplied by the appropriate concentration of dry matter to estimate forage mass. Occasionally, prior to obtaining the postgrazing forage mass, a dung pad had to be removed. The forage mass utilized (kg ha^{-1}) was determined by subtracting postgrazing forage mass from pregrazing forage mass.

Time and Handling

Forage samples were obtained for morphological separation and laboratory analyses the afternoon prior to defoliation. Four subsamples were cut by hand along each side of the pregrazing harvest strip (eight subsamples) to the same stubble height (5 cm). The subsamples were bulked into one for the subplot, placed in a plastic bag and preserved on ice until taken to the laboratory, refrigerated (4.4°C), and hand separations initiated. The samples were first separated into tall fescue and weeds (broad-leaved weeds and weedy grasses). The tall fescue was further separated morphologically into green leaf, green stem, and dead tissue. Samples that could not be separated within 24 h were frozen (−11°C) until separated. Once separated, the fractions were stored frozen (−26°C) until freeze dried. Following freeze drying, the sample fractions were weighed, and the samples ground through a Wiley mill to pass a 1-mm sieve and returned to the freezer (−26°C) until analyzed. The freeze-dried weights of the component fractions of the total sample were recorded and used to express the proportion of the forage mass that was "tall fescue" and "weeds" and the proportion of the tall fescue mass that was "green leaf," "green stem," and "dead tissue."

Animals

Angus steers were used to defoliate each subplot. In the first defoliation each year, steers purchased the previous spring were used and averaged 318, 283, and 298 kg in Years 1, 2, and 3, respectively. For all subsequent defoliations, a new set of steers was used each year and averaged, for the experiment, 244, 256, and 243 kg for Years 1, 2 and 3, respectively. Subplot

paddocks (9.2 by 9.2 m) were bounded on each side with electric polywire and the morning following the pregrazing sampling (described above) steers were randomly allocated to the appropriate defoliation treatment. Generally, three steers were allocated to each subplot; however, on occasion up to five steers were used depending on steer sizes and forage mass. Animals were permitted to graze each subplot until the accumulated forage was defoliated to about 7 to 10 cm. Thereafter, the animals were removed and the subplot sampled for residual forage mass. Defoliation was generally achieved during a 2- to 7- h grazing period. If steers quit grazing prior to adequate herbage removal they were removed from the subplot and returned in the same afternoon or the following morning for another grazing period. The rate and degree of defoliation was dependent on individual steer behavior, weather conditions, and the condition of the forage relative to frost damage (green vs. dead), and its presentation to the animal (i.e., erect vs. bedded down). Defoliation took an average of 3.5 h in Year 1, 4.9 h in year 2, and 5.0 h in Year 3.

Laboratory Analyses

All samples were scanned in a near-infrared reflectance spectrophotometer (NIRS) and the H statistic (0.6) was used to identify samples with different spectra. These samples were selected for use in laboratory analyses for the development of prediction equations.

In Vitro True Dry Matter Disappearance, Crude Protein, and Fiber Fractions

Samples were analyzed for in vitro true dry matter disappearance (IVTD) using ruminal inoculum collected from a cannulated, mature Hereford steer fed pure alfalfa (*Medicago sativa* L.) hay. After 48-h incubation with ruminal inoculum (Burns and Cope, 1974) in a batch fermenter (ANKOM Technology Corp., Fairpoint, NY) samples were extracted with neutral detergent solution in a batch processor (ANKOM Technology Corp., Fairpoint, NY) to determine IVTD. Crude protein (CP) was estimated as 6.25 times the percentage of N determined by auto analyzer (AOAC, 1990).

Fiber fractions, consisting of neutral detergent fiber (NDF), acid detergent fiber (ADF), sulfuric acid lignin, and acid detergent insoluble ash, were sequentially estimated according to Van Soest and Robertson (1980) in a batch processor (ANKOM Technology Corp., Fairpoint, NY). Hemicellulose (HEMI) was determined by subtracting ADF from NDF and cellulose by subtracting lignin plus ash from ADF.

Soluble Carbohydrate Extraction and Determination

Total nonstructural carbohydrate (TNC) and constituent starch, monosaccharides (MS), and disaccharides plus polysaccharides (D/PS) were analyzed as follows. Two, 0.5-g samples of each unknown, one with the starch to be hydrolyzed to glucose by amyloglucosidase and the other unhydrolyzed, were weighed into 125-mL flasks. Each flask received 15 mL of water and was placed on a hot plate and brought to a boil for 3 min to gelatinize the starch. After cooling, each flask received 10 mL of a buffer solution (pH = 4.45) containing three parts of 0.2 *M* acetic acid and two parts 0.2 *M* sodium acetate. The samples to be enzymatically hydrolyzed received an additional 10 ml of a 0.5% solution of amyloglucosidase (EC 3.2.1.3, Rhizopus mold, Sigma-Aldrich, St. Louis, MO). All samples were then stoppered and incubated at 38 to 44°C for 44 h with occasional swirling. After incubation, samples were filtered through a Whatman no. 40 filter paper into a 100-mL volumetric flask and brought to volume with deionized water. This extract was used for TNC and constituent carbohydrate analyses. Enzyme blanks containing water, buffer, and enzyme were included in each run. In addition, a starch source was used to confirm the activity of the enzyme. All sample extracts were analyzed using the appropriate chemistry cartridge (below) in a Technicon Auto Analyzer (Technicon Industries Systems, Tarrytown, NY).

The TNC were determined on the extract from the hydrolyzed samples using the Total Sugar/Reducing Sugar cartridge according to Bran and Luebbe's colorimetric method G-227-99, Rev. 2 (Bran and Luebbe Auto Analyzer Methods, Roselle, IL). The extracts were first treated in-line with HCl at 90°C to chemically hydrolyze D/PS to reducing sugars. All reducing sugars were then reacted in-line with *p*-hydroxybenzoic acid hydrozide, which in alkaline medium at 85°C forms a yellow osazone, and the absorbance measured at 420 nm and the concentration of TNC determined. The extracts from the unhydrolyzed samples were analyzed for reducing sugars as noted for TNC, but without the addition of HCL, giving the concentrations of only the naturally occurring MS.

The extracts from both the hydrolyzed and unhydrolyzed samples were analyzed for glucose according to Bran and Luebbe's colorimetric method G-142-95, Rev. 1 (Bran and Luebbe Auto Analyzer Methos). The starch concentrations were calculated as [(mg glucose from the hydrolyzed extract − mg glucose from the enzyme blank) − mg glucose from the unhydrolyzed extract] (0.90 mg^{-1} dry sample) (0.90 is a factor used to convert milligrams of glucose to milligrams of starch; AOAC, 1990). The D/PS were determined by subtracting the concentrations of starch plus MS from the TNC concentrations.

Ergovaline Determination

Ergovaline analysis was conducted according to Hill et al. (1993) on a reduced set of samples. The set consisted of two replicates of the three canopy fractions from three (i.e., October grazed and December and February stockpiled) of the five defoliation treatments harvested in Years 1 and 3 for the endophyte-free and MaxQ samples (n = 72). Because the wild-type forage was expected to have ergovaline present, and ergovaline can be predicted using NIRS (Roberts et al., 1997), a subset of samples was selected including the categories noted above for the endophyte free and MaxQ but included samples from Year 2 and all five defoliation treatments (n = 90). This produced a data set based on laboratory determination of ergovaline for comparisons among endophyte status as well as permitting NIRS calibration and prediction for the entire set of samples from the wild-type forage.

Near Infrared Predictions

Laboratory values from the analyzed samples were used to develop NIRS calibration equations with acceptable standard errors of calibration and cross validation. These were subsequently used to predict individual observations for each constituent analyzed (Table 1).

Statistical Analyses

Data were analyzed statistically in combined analyses with years treated as repeated measures using a mixed model (PROC MIXED; SAS Institute, 1995). In the mixed model,

Table 1. The range for each forage constituent predicted by near-infrared reflectance spectrophotometry, its SE of calibration (SEC), and SE of cross-validation (SEV) for appropriate data sets.

Variable†	N	Range	Mean	Calibration		Validation	
				SEC	R^2‡	SEV	R^2
A. Nutritive Value				g kg^{-1}			
Green leaf, green stem, and dead							
IVTD	89	502–935	815	10.2	0.992	15.8	0.981
CP	88	61–266	125	2.4	0.997	4.4	0.990
NDF	83	328–747	493	8.0	0.995	10.4	0.991
ADF	81	171–386	246	4.0	0.996	5.9	0.991
CELL	83	156–339	227	4.6	0.992	5.8	0.987
Lignin	81	5–59	19	1.2	0.993	1.9	0.981
Green leaf and green stem							
Glucose	72	25–78	53	1.0	0.994	4.0	0.987
MS	73	68–300	164	3.5	0.994	7.7	0.970
Starch	74	7–49	22	2.7	0.947	3.6	0.905
TNC	71	69–544	313	3.6	0.999	5.6	0.998
Dead							
Glucose	50	3–26	9	1.3	0.935	1.9	0.869
MS	48	2–70	18	2.1	0.984	5.2	0.903
Starch	46	<1–44	7	2.6	0.986	3.2	0.772
TNC	49	4–88	30	1.0	0.997	7.1	0.887
B. Ergovaline				μg kg^{-1}			
Green leaf	28	20–340	165	22	0.940	32	0.876
Green stem	28	180–1730	745	24	0.996	200	0.703
Dead	29	10–100	43	8	0.899	18	0.473

† IVTD, in vitro true dry matter disappearance; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; CELL, cellulose; MS, monosaccharide; TNC, total nonstructural carbohydrates.
‡ R^2 = coefficient of determination.

treatments were considered fixed whereas years and replicates were considered random. The endophyte status (i.e., wild type, MaxQ, or free), when significant, was examined using single degree contrast statements to compare MaxQ vs. wild type and MaxQ vs. free within the analyses of variance. The defoliation managements consisted of grazing (two defoliations each year) and stockpile (one defoliation each year) and were compared using a single degree of freedom contrast statement within the analyses of variance. The forage mass data for the grazing treatment are the total of the two defoliations within year, whereas the composition data are means weighted for forage mass. Because the stockpile treatments consisted of a time interval for accumulation prior to utilization they were evaluated using trend (linear, quadratic, and lack of fit) analyses within the analyses of variance.

A second analysis of variance was conducted for the three endophyte treatments managed by only the grazing treatment. Unlike the stockpile management, this treatment was defoliated by grazing two times in the autumn each of the 3 yr. Forage from the autumn grazings was compared for endophyte status effects by using the same two contrast statements noted above and responses from the two defoliation dates were tested in the analyses of variance. Differences were tested at $P \leq 0.05$ unless otherwise stated.

RESULTS AND DISCUSSION

The climatological data show that in each of the 3 yr of this study the rainfall in June and July as well as for August, the month forage accumulation was initiated, was generally favorable for forage growth with temperatures near normal (Table 2). Some monthly rainfall deficits are noted but all were <25 mm (Table 2). During the stockpile period (September through February) when both forage growth and tissue weathering can occur, rainfall was below average in Years 1 and 2 with

Table 2. Thirty-year means and departures from the mean for climatological data recorded approximately 5 km from the experimental site.†

Month	30-yr mean		Departures from the mean							
			Year 1		Year 2		Year 3		Year 4	
	Rainfall	Temp.	Rainfall	Temp.	Rainfall	Temp.	Rainfall	Temp.	Rainfall	Temp.
	mm	°C	mm	°C	mm	°C	mm	°C	mm	°C
January	102.1	4.3	–	–	−69.1	1.0	49.5	1.7	−55.4	−1.7
February	88.1	6.1	–	–	−28.7	2.3	−55.9	0.9	29.7	−1.1
March	102.4	10.4	–	–	78.2	−0.9	3.8	1.0	30.5	1.4
April	71.1	15.1	–	–	−27.4	0.9	−42.4	2.3	42.4	−0.5
May	96.3	19.4	–	–	−6.6	0.6	−67.6	0.0	12.5	−0.4
June	86.9	23.7	−23.4	1.3	28.5	1.2	−17.0	1.8	18.8	−0.6
July	109.0	26.0	48.3	−1.1	−4.1	−1.4	11.9	0.9	2.8	−0.3
August	96.0	25.1	72.6	−0.6	27.9	1.3	−18.8	0.8	121.7	0.9
September	108.2	21.8	−11.2	−1.1	−86.4	1.2	−19.6	1.1	5.3	−0.7
October	80.8	15.6	−80.8	0.1	−33.5	−0.3	156.7	0.9	−14.2	−0.2
November	75.4	10.7	−10.4	−1.7	−62.7	2.7	17.3	−1.2	−29.5	3.1
December	77.2	6.1	−38.9	−4.2	−26.2	2.6	50.8	−2.5	12.2	−1.1

† Data recorded at the Raleigh-Durham International Airport and reported by the National Oceanic and Atmospheric Administration.

the exception of January in Year 2 (calendar Year 3). Further, monthly temperatures were generally above average. The rainfall in the third year was above average and associated temperature below average in October, November, December, and February (Table 2). Environmental variation causes shifts in forage growth and in tissue weathering. The present analysis of repeated measures focuses on the overall treatment effect based on individual years in order to estimate what is likely to occur from the treatments in any year. However, some special cases will be discussed in which year to year variation provides some insight.

Defoliation Management

Analyses of the forage mass and composition data generally showed no interaction between endophyte status and the defoliation treatments. An exception was dead tissue composition, specifically ADF and cellulose concentrations. This interaction was minor and due to differences in the magnitude of change that occurred from October to February among endophyte status. Consequently, the data are presented by main effects.

Rotational stocking associated with the subplots could result in variable defoliation from subplot to subplot at any one defoliation date. This was tested by comparing total forage mass (tall fescue plus "other") pre- and postgrazing (Table 3). In general, the forage mass pregrazing and the residual forage mass postgrazing were similar among the three endophyte treatments indicating that the degree of defoliation was similar among the endophyte treatments. This was also reflected by similar mean compressed canopy heights among the endophyte treatments at the start (mean = 12 cm; $P = 0.21$) and at the end (mean = 6.7 cm; $P = 0.22$) of grazing. The percentages of reduction in compressed height among endophyte treatments were similar but approached significance ($P = 0.07$) and the contrasts of MaxQ with endophyte free showed the latter to be significantly less ($P = 0.05$). However, this difference was small and unlikely to have impacted other variables.

The grazed treatment, because it was the sum of two defoliations, resulted in a greater total forage mass and residue compared with the stockpile managements (6160 vs. 3920 kg ha^{-1}) while the forage removed was similar between grazing and the stockpiled defoliation treatments (Table 3). At start of grazing, the compressed forage height was least for the grazed treatment (a mean of two defoliations) but similar to the stockpile after grazing resulting in the least reduction (33 vs. 46%). No trends were noted among the stockpile treatments in total forage mass, quantity of forage mass removed, or in the residue (Table 3). Initial compressed heights and ending compressed heights were similar, being within 2 cm. The percentage of reduction between the starting and ending compressed heights was similar, but the quadratic trend approached significance ($P = 0.07$) as heights first increased and then decreased with a maximum at the December defoliation.

The experimental plan included the opportunity to evaluate tall fescue regrowth after repeated defoliation following August for the grazing management and after initial defoliation for each of the stockpile treatments. However, only two defoliations occurred for the grazing management and no regrowth in any of the years approached 15 cm following defoliation of the initial stockpile. This lack of autumn regrowth was somewhat

Table 3. Total (fescue plus weeds) forage mass, forage removed by grazing and reduction in compressed height of stands without and with wild type and MaxQ endophytes when grazed or after stockpiled until mid-February.

Item	Forage mass			Compressed		
	Total	Removed	Residue	Start	End	Reduction
	kg ha^{-1}			cm		%
Endophyte†						
Wild type (W)	4320	1370	2950	13	7	44
MaxQ (MQ)	4450	1450	3000	12	7	44
Free (F)	4330	1200	3130	11	6	41
Significance (*P*)	0.91	0.42	0.86	0.21	0.22	0.07
MQ vs. W	0.71	0.68	0.88	0.65	0.54	0.99
MQ vs. F	0.73	0.21	0.71	0.20	0.24	0.05
Defoliation:						
Grazed (G)‡	6160	1270	4890	9	6	33
Stockpile (S)§	3920	1360	2560	13	7	46
November¶	4100	960	3140	13	8	41
December	3890	1640	2240	13	7	50
January	4140	1600	2540	12	6	48
February	3550	1240	2310	12	7	45
Significance (*P*)						
G vs. S	0.01	0.78	<0.01	<0.01	0.28	<0.01
S Trend#						
L	0.61	0.56	0.25	0.10	0.09	0.44
Q	0.76	0.11	0.42	0.94	0.12	0.07
LOF	0.63	0.75	0.36	0.76	0.82	0.57

† Each value is the mean of five defoliation treatments, 3 yr, and three replicates ($n = 45$).
‡ Each value is the mean of two defoliation, three endophyte conditions, 3 yr, and three replicates (n = 54), except for total forage mass which is the total of two defoliation (n = 27).
§ Each value is the mean of four stockpile treatments, three endophyte conditions, 3 yr, and three replicates (n = 108).
¶ Each value is the mean of three endophyte conditions, 3 yr, and three replicates ($n = 27$).
# L, linear; Q, quadratic; LOF, lack of fit.

surprising, especially following the mid-November grazing based on previous experience with other tall fescue cultivars, namely 'Kentucky 31' and 'Triumph,' and may be a characteristic of Jesup.

Forage Mass and Nutritive Value

Neither the forage mass of tall fescue nor its nutritive value (ergovaline is an exception and will be addressed later) was altered by the presence or absence of the MaxQ or wild-type endophytes (Table 4). Grazing management resulted in a greater tall fescue mass (because it was the sum of two defoliations) and it had greater concentrations of IVTD and CP but decreased concentrations of HEMI compared with forage from the stockpile managements. When the period of autumn accumulation was extended by delaying grazing through mid-February, changes in tall fescue mass and the weedy fraction showed no trend while canopy height declined linearly.

The year-to-year differences in tall fescue mass were large (data not shown) and deserve some mention relative to degree of utilization. The mass obtained at the November grazing in this study averaged 3190, 5960, and 3160 kg ha^{-1} for Years 1, 2, and 3, respectively. This compares with yields of 2920 to 3710 kg ha^{-1} from a previous study conducted at the same location when stockpiled from 1 August and harvested in mid-November (Burns and Chamblee, 2000). Tall fescue mass among the four stockpile treatments in Year 1 of this study ranged from 3050 kg ha^{-1} (February defoliation) to 3980 kg ha^{-1} (January defoliation) with the grazing management treatment averaging 6240 kg ha^{-1} (the sum of two grazing periods). In Year 2, however, tall fescue mass for all treatments was greater and for the stockpile treatments ranged from 4810 kg ha^{-1} (February defoliation) to 5960 kg ha^{-1} (November defoliation) with the grazing management treatment averaging 8790 kg ha^{-1}. Much of the variation in tall fescue mass among years was attributed to normal or above-normal rainfall in June, July, and August and normal to above normal temperatures in August through December in Year 2 (Table 2). In Year 3, yields from the stockpiled treatments were generally of the magnitude obtained in Year 1 ranging from 2780 kg ha^{-1} (February defoliation) to 3590 kg ha^{-1} (January defoliation) with the grazing management treatment averaging 6570 kg ha^{-1} (the sum of two defoliation periods) The relatively greater tall fescue mass for the grazing management treatment in Year 3 was attributed to above-normal rainfall in October and November which stimulated regrowth following the initial grazing.

The degree of utilization in the stockpile treatments was influenced by the presence of dead tissue. Dead tissue averaged (over all treatments) 1190 kg ha^{-1} in Year 1, 2410 kg ha^{-1} in Year 2, and 850 kg ha^{-1} in Year 3. Steers were adept at selecting the green tissue as a moderately green pasture pregrazing became a totally brown pasture postgrazing. For example, in Year 2, when appreciable dead tissue was present, the dry matter concentration of the postgrazed forage from the February-stockpile was 720 g kg^{-1}, indicating that the pasture was essentially dead plant tissue. Because animals were not retained on the pastures to accomplish maximum defoliation, a high proportion of the available forage pregrazing in Year 2 was left as residue. The apparent discrepancy between forage removed and compressed height is associated with the shifts in the pro-

Table 4. Tall fescue (TF) and weedy fraction mass and nutritive value† of TF without and with wild type and MaxQ endophytes and grazed or after stockpiled until mid-February (dry matter basis).

	Mass			Fiber fractions							Carbohydrates			
Item	TF	Weeds	Height‡	IVTD	CP	NDF	ADF	HEMI	CELL	Lignin	MS	D/PS	St	TNC
	kg ha^{-1}		cm	g kg^{-1}										
Endophyte§														
Wild type	4250	70	34	730	126	553	288	265	254	30	97	68	12	177
MaxQ	4420	30	34	731	129	552	286	266	252	30	97	66	12	174
Free	4140	190	33	736	127	553	286	267	253	30	97	66	13	177
Significance (*P*)	0.81	0.36	0.72	0.74	0.80	0.99	0.90	0.94	0.86	0.96	0.99	0.80	0.50	0.86
Defoliation														
Grazed (G)¶	5890	270	33	769	173	522	275	247	244	27	108	33	14	153
Stockpile (S)#	3870	60	34	722	116	561	290	271	255	31	94	75	12	181
November††	4010	100	41	763	125	522	273	249	243	26	116	86	16	220
December	3780	110	35	738	117	533	277	256	244	29	106	92	14	211
January	4140	0	32	715	104	565	291	274	257	31	96	82	11	189
February	3530	10	29	675	118	620	317	303	277	37	59	42	8	107
Significance (*P*)														
G vs. S	0.01	0.07	0.59	0.04	<0.01	0.11	0.22	.05	0.27	0.14	0.34	0.08	0.09	0.39
S Trend‡‡														
L	0.68	0.41	<0.01	<0.01	0.25	<0.01	0.01	<0.01	.01	<0.01	0.01	0.14	<0.01	0.02
Q	0.74	0.97	0.31	0.68	0.12	0.28	0.30	0.28	0.28	0.31	0.28	0.27	0.70	0.23
LOF	0.55	0.60	0.85	0.82	0.25	0.97	0.95	0.99	0.92	0.59	0.65	0.89	0.99	0.73

† IVTD, in vitro true dry matter disappearance; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; HEMI, hemicellulose; CELL, cellulose; MS, monosaccharides; D/PS, di- and polysaccharides; St, starch; TNC, total nonstructural carbohydrates.
‡ Extended leaf.
§ Each value is the mean of five defoliation treatments, 3 yr, and three replicates (n = 45).
¶ Each value is the weighted mean of two defoliations, three endophyte conditions, 3 yr, and three replicates (n = 54), except for mass which is the total of two defoliations (n = 27).
# Each value is the mean of four stockpile treatments, three endophyte conditions, 3 yr, and three replicates (n = 108).
†† Each value is the mean of three endophyte conditions, 3 yr, and three replicates (n = 27).
‡‡ L, linear; Q, quadratic; LOF, lack of fit.

portion of green and dead tissue with the latter being more compressible.

Within the stockpile, the concentration of IVTD of the tall fescue forage declined linearly while NDF and other fiber fractions increased linearly as grazing was delayed until mid-February (Table 4). Crude protein did not vary significantly ($P = 0.12$). The changes noted for IVTD, CP, and NDF are consistent with the literature (Ross and Reynolds, 1979; Burns and Chamblee, 2000; Kallenbach et al., 2003). The TNC concentrations decreased linearly from mid-November to mid-February as noted in previous reports (Balasko, 1977; Rayburn et al., 1979; Collins and Balasko, 1981; Burns and Chamblee, 2000). The MS and starch concentrations declined similarly to TNC in response to the stockpiling treatments whereas the D/PS showed no significant trends. The general declining trend in TNC and increasing trends for NDF and its constituents are indicative of reduced nutritive value of the stockpile.

Tall Fescue Fractions

Green Leaf Tissue

Averaged over the endophyte treatments, the green leaf tissue of the tall fescue mass accounted for 45% of the whole plant dry matter giving a leaf mass of 1930 kg ha^{-1}. Neither the leaf percentage of the tall fescue mass nor the leaf mass itself were altered by the presence or absence of the MaxQ or wild-type endophytes (Table 5). Grazing management resulted in greater tall fescue leaf mass compared with stockpile because it was the sum of two defoliations. Delaying grazing of the stockpile resulted in a linear decrease in leaf percentage with the proportion declining from 54% in mid-November to 31% by mid-February. These changes are consistent with those reported by Taylor and Templeton (1976), Archer and Decker (1977), and Burns and Chamblee (2000). The change in leaf mass was not significant ($P = 0.15$).

The IVTD of the leaf tissue was the only nutritive value estimate altered by the presence of the endophyte. In this case IVTD of the endophyte-free forage was greater (865 g kg^{-1}) than the MaxQ forage (858 g kg^{-1}, Table 5). Tall fescue leaf from grazing management, compared with stockpile, had greatest concentrations of CP, ADF, cellulose, and lignin but least TNC. The increase in TNC in the stockpile is associated through dilution with decreases in the fiber fractions and, in part, to maintaining IVTD similar to the grazed forage ($P = 0.09$). Delaying defoliation of the stockpile from November to February showed a linear reduction in ADF and lignin. The mean TNC concentration is appreciably greater than reported by Taylor and Templeton (1976) or by Burns and Chamblee (2000) but samples consisted only of green leaves in this case compared with green leaves and stems in the latter cases.

Green Stem Tissue

The green stems contributed an average of 13% of the tall fescue dry matter giving a mean stem mass of 560 kg ha^{-1} and neither variable was altered by the presence of the endophytes (Table 6). Tall fescue mass had similar proportions of green stem from the grazed and stockpile treatments, but stem mass was greater from the grazed treatment because it was the sum of two defoliation periods (Table 3). The proportion of stem and stem mass in

Table 5. Proportion of tall fescue that is green leaf, green leaf mass, and nutritive value† without and with wild type and MaxQ endophytes and grazed or stockpiled until mid-February (dry matter basis).

						Fiber fractions				Carbohydrates			
Item	Prop.‡	Mass	IVTD	CP	NDF	ADF	HEMI	CELL	Lignin	MS	D/PS	St	TNC
	%	kg ha^{-1}	g kg^{-1}										
Endophyte§													
Wild type	46	1940	856	161	436	223	214	204	15	148	97	12	257
MaxQ	45	2030	858	166	436	221	215	203	15	147	93	11	250
Free	45	1820	865	166	431	218	213	201	15	148	95	12	255
Significance (*P*)	0.87	0.51	0.02	0.65	0.45	0.31	0.72	0.45	0.27	0.90	0.78	0.30	0.71
Defoliation													
Grazed (G)¶	61	3590	836	208	458	243	215	221	20	133	34	13	178
Stockpile (S)#	41	1510	866	153	428	215	214	198	14	151	110	11	274
November††	54	2050	848	151	441	231	210	213	16	160	96	14	271
December	46	1580	857	151	428	217	211	200	14	156	116	11	283
January	35	1390	872	138	414	205	209	190	12	163	138	11	312
February	31	1040	886	173	430	205	225	191	13	126	92	10	227
Significance (*P*)													
G vs. S	<0.01	<0.01	0.09	<0.01	0.22	0.02	0.9	0.03	<0.01	0.25	0.02	0.14	0.03
S Trend‡‡													
L	<0.01	0.15	0.07	0.30	0.62	0.04	0.40	0.07	0.03	0.16	0.93	<0.01	0.50
Q	0.57	0.90	0.84	0.15	0.48	0.42	0.52	0.40	0.32	0.25	0.19	0.30	0.17
LOF	0.57	0.84	0.90	0.26	0.74	0.78	0.71	0.83	0.55	0.38	0.54	0.34	0.39

† IVTD, in vitro true dry matter disappearance; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; HEMI, hemicellulose; CELL, cellulose; MS, monosaccharides; D/PS, di- and polysaccharides; St, starch; TNC, total nonstructural carbohydrates.
‡ Prop., proportion of dry matter.
§ Each value is the mean of five defoliation treatments, 3 yr, and three replicates ($n = 45$).
¶ Each value is the mean of two defoliations, three endophyte conditions, 3 yr, and three replicates ($n = 54$), except mass which is the total of two defoliation ($n = 27$).
# Each value is the mean of four stockpile treatments, three endophyte conditions, 3 yr, and three replicates ($n = 108$).
†† Each value is the mean of three endophyte conditions, 3 yr, and three replicates ($n = 27$).
‡‡ L, linear; Q, quadratic; LOF, lack of fit.

Table 6. Proportion of tall fescue that is green stem, green stem mass, and nutritive value† without and with wild type and MaxQ endophytes and grazed or stockpiled until mid-February (dry matter basis).

						Fiber fractions				Carbohydrates			
Item	Prop.‡	Mass	IVTD	CP	NDF	ADF	HEMI	CELL	Lignin	MS	D/PS	ST	TNC
	%	kg ha^{-1}	g kg^{-1}										
Endophyte§													
Wild type	13	560	866	94	444	216	228	203	10	173	189	30	392
MaxQ	13	590	870	95	444	215	229	202	10	179	181	29	389
Free	13	530	874	96	445	212	232	200	10	174	178	28	385
Significance (*P*)	0.87	0.83	0.07	0.89	0.97	0.45	0.05	0.56	0.51	0.39	0.55	0.16	0.79
Defoliation													
Grazed (G)¶	14	840	830	110	519	264	255	247	15	172	78	36	286
Stockpile (S)#	12	490	880	91	425	202	224	190	9	176	209	27	414
November††	16	630	875	82	429	211	218	198	10	178	230	33	448
December	14	540	880	87	410	198	213	185	9	181	240	27	448
January	13	520	880	91	414	195	219	185	8	180	220	23	423
February	8	270	883	106	448	204	244	194	8	165	148	24	337
Significance (*P*)													
G vs. S	0.17	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	0.75	<0.01	<0.01	<0.01
S trend‡‡													
L	<0.01	0.02	0.59	0.03	0.36	0.45	0.05	0.75	<0.01	0.38	0.04	<0.01	0.01
Q	0.15	0.41	0.90	0.47	0.09	0.17	0.09	0.15	0.15	0.41	0.13	0.01	0.12
LOF	0.48	0.45	0.86	0.63	0.92	0.98	0.84	0.93	0.59	0.85	0.84	0.42	0.76

† IVTD, in vitro true dry matter disappearance; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; HEMI, hemicellulose; CELL, cellulose; MS, monosaccharides; D/PS, di- and polysaccharides; St, starch; TNC, total nonstructural carbohydrates.
‡ Proportion of dry matter.
§ Each value is the mean of five defoliation treatments, 3 yr, and three replicates (n = 45).
¶ Each value is the mean of two defoliations, three endophyte conditions, 3 yr, and three replicates (n = 54), except mass which is the total of two defoliations (n = 27).
# Each value is the mean of four stockpile treatments, three endophyte conditions, 3 yr, and three replicates (n = 108).
†† Each value is the mean of three endophyte conditions, 3 yr, and three replicates (n = 27).
‡‡ L, linear; Q, quadratic; LOF, lack of fit.

the stockpile decreased linearly as grazing was delayed until mid-February. Stem compositional changes associated with endophyte status were noted only for HEMI, but the differences were small (Table 6). MaxQ and the wild type had similar HEMI concentrations, but MaxQ was less compared with the endophyte free.

Stem tissue from the stockpiled treatments, compared with grazed, had greatest nutritive value (IVTD) as indicated by greatest TNC and least NDF and its constitute fiber fractions. The exception was CP, which was least in the stockpile stems. The large increase in TNC in the stockpile stems resulted from the increase in the D/PS concentrations (209 g kg^{-1}) compared with concentration found in the grazed treatment (78 g kg^{-1}).

Delaying the utilization of the stockpile to February showed a linear increase in stem CP and HEMI along with a decrease in lignin and TNC. The D/PS fractions of the TNC showed the largest change with concentrations declining from a high of 240 g kg^{-1} in December to 148 g kg^{-1} by February.

Dead Tissue

The proportion of the tall fescue mass composed of dead tissue averaged 42% resulting in a dead mass of 1780 kg ha^{-1} (Table 7). Neither the proportion, nor the dead mass, nor the nutritive value of the dead tissue, were altered by endophyte status. The proportion of the dead tissue mass and the dead tissue mass were greater in the stockpile compared with the grazed treatment and both increased linearly as utilization of the stockpile was delayed to February (dead proportion increased from 31 to 61% and mass from 1330 to 2220 kg ha^{-1}).

The IVTD of the harvested dead plant material averaged 562 g kg^{-1} and was not altered when grazing was delayed to mid-February. This same relationship was reported previously by Taylor and Templeton (1976) and Burns and Chamblee (2000). The TNC concentration of the dead tissue was not as great as noted for the leaf and stem tissues but was the only constituent that first increased to mid-January and then decreased by mid-February resulting in a quadratic trend.

Ergovaline Concentrations and Relationships

Ergovaline concentrations of the reduced data set (Years 1 and 3 and October grazed and December and February stockpiles) showed endophyte status × defoliation treatment interactions ($P < 0.01$) for the whole canopy, and canopy leaf and stem fractions. These were simply nonparallel trends as grazing was delayed until February and therefore we averaged over these effects.

Ergovaline concentrations of the canopies were altered by endophyte status with MaxQ having a concentration that was less than the wild type ($P = 0.05$) but similar to the endophyte free (Table 8). The canopy of the October grazed treatment had greater ergovaline than the stockpile showing that stockpiling can be used as a method of reducing ergovaline concentrations (Kallenbach et al., 2003). Ergovaline concentrations of leaf and stem, but not dead tissue were altered by endophyte status. MaxQ had concentrations that were less than the wild-type, but similar to the endophyte free. Ergovaline changes in leaf, stem, and dead fractions as grazing of the stockpile was delayed from December to February, were not significant (Table 8).

Table 7. Proportion of tall fescue that is dead, dead mass, and nutritive value† without and with wild-type and MaxQ endophytes and grazed or stockpiled until mid-February (dry matter basis).

						Fiber fractions				Carbohydrates			
Item	Prop.‡	Mass	IVTD	CP	NDF	ADF	HEMI	CELL	Lignin	MS	D/PS	St	TNC
Endophyte§	%	kg ha^{-1}	g kg^{-1}										
Wild type	42	1750	557	98	713	377	336	319	52	15	2	8	24
MaxQ	42	1800	559	104	708	337	335	315	52	15	2	8	24
Free	43	1790	569	99	712	375	337	321	51	18	3	10	30
Significant (*P*)	0.71	0.96	0.39	0.38	0.82	0.38	0.96	0.32	0.61	0.34	0.41	0.41	0.18
Defoliation													
Grazed (G)¶	25	1460	575	125	682	360	322	301	51	10	3	6	17
Stockpile (S)#	46	1860	558	94	718	379	340	322	52	18	2	9	28
November††	31	1330	558	100	712	376	336	317	52	8	4	11	22
December	41	1670	559	96	708	376	333	319	52	21	2	12	33
January	52	2230	571	87	713	375	338	323	49	30	3	8	42
February	61	2220	545	94	740	389	352	332	54	13	1	6	16
Significance (*P*)													
G vs. S	<0.01	0.04	0.32	<0.01	0.06	0.04	0.12	0.02	0.50	0.28	0.54	0.17	0.22
S trend‡‡													
L	<0.01	<0.01	0.67	0.34	0.22	0.25	0.25	0.17	0.98	0.44	0.19	0.06	0.75
Q	0.94	0.26	0.34	0.41	0.32	0.33	0.38	0.63	0.07	0.05	0.63	0.44	0.04
LOF	0.73	0.25	0.45	0.52	0.83	0.62	0.99	0.98	0.09	0.41	0.22	0.60	0.34

† IVTD, in vitro true dry matter disappearance; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; HEMI, hemicellulose; CELL, cellulose; MS, monosaccharides; D/PS, di- and polysaccharides; St, starch; TNC, total nonstructural carbohydrates.
‡ Proportion of dry matter.
§ Each value is the mean of five defoliation treatments, 3 yr, and three replicates (n = 45).
¶ Each value is the weighted mean of two defoliations, three endophyte conditions, 3 yr, and three replicates (n = 54), except mass which is the total of two defoliations (n = 27).
# Each value is the mean of four stockpile treatments, three endophyte conditions, 3 yr, and three replicates (n = 108).
†† Each value is the mean of three endophyte conditions, 3 yr, and three replicates (n = 27).
‡‡ L, linear; Q, quadratic; LOF, lack of fit.

The proportion of the canopy dry matter that consists of leaf, stem, and dead fractions, for this reduced data set were similar to those observed for the total data set (Tables 5, 6, and 7).

Wild-type Endophyte and Ergovaline

Because of the apparent relationship between the presence of ergovaline and fescue toxicosis, the greater ergovaline concentrations in Jesup with the wild-type endophyte, and the differences in both the proportion and ergovaline concentrations of the leaf, stem, and dead fractions of the canopy, further examination is warranted. Using the complete data set (i.e., all years, all defoliation treatments, and all replicates) for the wild-type endophyte, ergovaline concentrations of tall fescue declined linearly ($P < 0.01$) as did the concentrations in the leaf and stem fractions ($P < 0.01$) as grazing was delayed (Fig. 1A). The dead tissue initially increased in ergovaline then declined as grazing was delayed resulting in a quadratic ($P = 0.04$) trend.

Table 8. Ergovaline concentrations of the tall fescue from the grazed and stockpile treatments, and the proportion and ergovaline concentration of the leaf, stem, and dead fractions (dry matter basis).

		Tall fescue fractions					
	Tall fescue	Leaf		Stem		Dead	
Item	EVL†	Prop.‡	EVL†	Prop.‡	EVL†	Prop.‡	EVL†
	μg kg^{-1}	%	μg kg^{-1}	%	μg kg^{-1}	%	μg kg^{-1}
Endophyte§							
Wild type (W)	221	49	183	12	709	39	41
MaxQ (MQ)	57	52	41	12	184	35	12
Free (F)	6	53	5	11	7	37	4
Significance (*P*)	0.06	0.46	<0.01	0.53	0.04	0.49	0.12
MQ vs. W	0.05	0.30	<0.01	0.76	0.04	0.28	0.10
MQ vs. F	0.33	0.97	0.10	0.31	0.26	0.70	0.50
Defoliation:							
Grazed (G)¶	174¶	66	144	14	524	21	19
Stockpile (S)#	55	44	43	10	188	45	19
December††	91	55	69	14	259	31	29
February	19	34	16	7	117	59	9
Significance (*P*)							
G vs. S	0.05	<0.01	0.02	0.43	0.03	0.02	0.98
Dec. vs. Feb.	0.15	<0.01	0.10	0.19	0.22	0.02	0.13

† EVL, ergovaline (determined by laboratory analysis).
‡ Prop., proportion of the canopy dry matter.
§ Each value is the mean of three defoliation dates, 2 yr, and two replicates (n = 12).
¶ Each value is the mean of three endophyte conditions, 2 yr, and two replicates (n = 12).
# Each value is the mean of two stockpile treatments, three endophyte conditions, 2 yr, and two replicates (n = 24).
†† Each value is the mean of three endophyte conditions, 2 yr, and two replicates (n = 12).

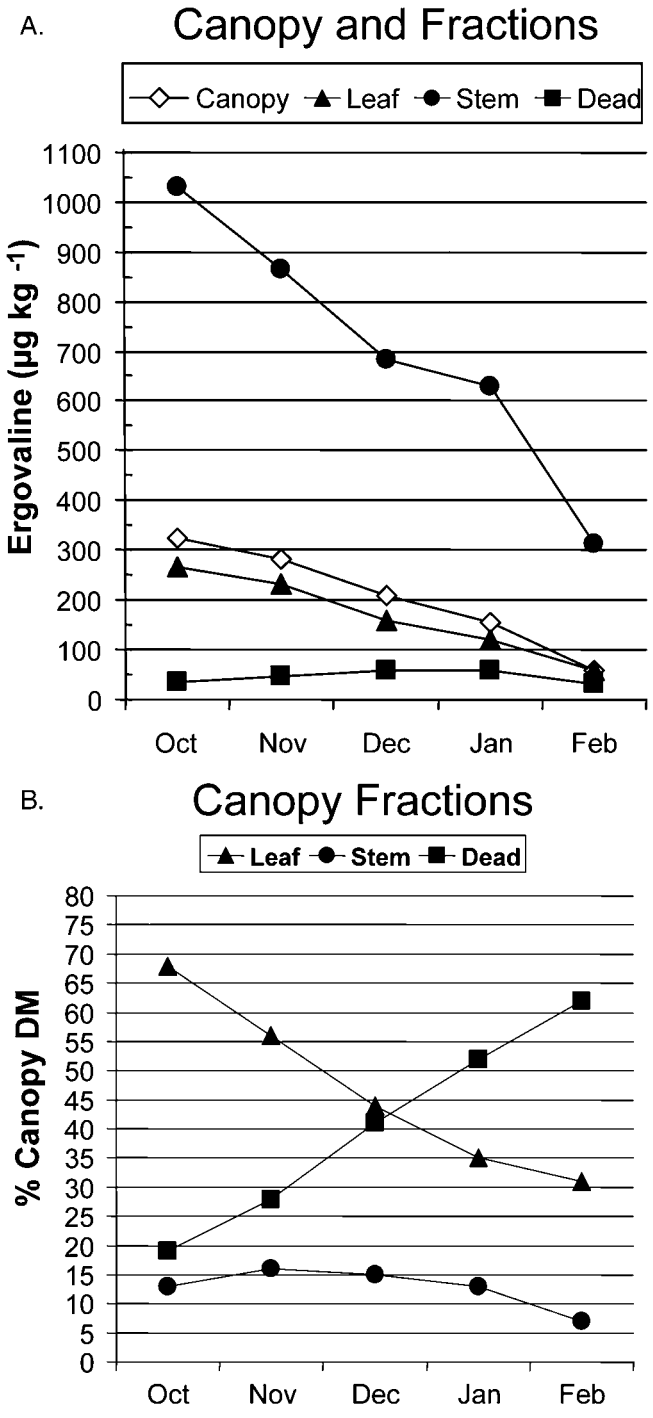

Fig. 1. (A) Changes in ergovaline concentrations (near-infrared reflectance [NIR] predicted) of grazed (October defoliation only) and stockpiled Jesup with the wild-type endophyte for canopy (SE = 35.6 µg kg^{-1}) and for the leaf (SE = 22.1 µg kg^{-1}), stem (SE = 126.2 µg kg^{-1}), and dead (SE = 10.4 µg kg^{-1}) fractions, and (B) the proportion of the tall fescue mass that is leaf (SE = 6.1%), stem (SE = 2.3%), and dead (SE = 6.9%) tissue (mean of three replicates and 3 yr).

Leaf tissue, as a proportion of the tall fescue mass (Fig. 1B) decreased linearly ($P < 0.01$), while the dead tissue increased linearly ($P < 0.01$), and stems showed a quadratic ($P = 0.03$) response. The associated ergovaline concentrations in tall fescue essentially parallel the concentrations found in the leaf tissue, not being greatly altered either by the large increase in dead tissue (because of its low ergovaline concentration of <60 µg kg^{-1}) or by the high ergovaline concentration of the stems (because of their relatively low presence in the canopy, i.e., <18%).

Differences among years in ergovaline concentrations were evident in the tall fescue mass and could account, in part, for varying degrees of toxicosis when stockpiled forage is grazed by cattle. For example, ergovaline concentrations of tall fescue in Years 1 and 2 were similar averaging 168 and 185 µg kg^{-1}, respectively, compared with 262 µg kg^{-1} for Year 3 (data not shown). Selecting data from Years 2 and 3 out of Fig. 1 as representative of the extremes, shows greater concentrations of ergovaline in tall fescue from the grazed treatment for Year 3 with concentrations declining and becoming similar in the stockpile in both years by February (Fig. 2A).

Differences between Years 2 and 3 in ergovaline concentration of leaf and stem fractions were evident, but not for the dead fraction (Fig. 2B). However, the proportion of tall fescue that consisted of leaf and dead tissue varied widely between years with leaf tissue declining and dead tissue increasing (Fig. 2C). Examining the relationships using simple correlation (r) between the proportion of the tall fescue mass each fraction contributes and their respective ergovaline concentrations relative to the tall fescue mass concentrations ($n = 12$) shows the leaf proportion to be closely related to the tall fescue mass ergovaline ($r = 0.93$; $P < 0.01$), the stem moderately related ($r = 0.66$; $P = 0.03$), and the dead fraction moderately but negatively related ($r = -0.63$; $P = 0.03$). The proportion of the leaf in the tall fescue mass is the key factor related to ergovaline concentration.

Quantity of Digestible Dry Matter, Crude Protein, and Total Nonstructural Carbohydrates

The quantities of digestible dry matter (DDM), CP, or TNC produced per hectare (concentrations in tall fescue × tall fescue mass) were not altered for the tall fescue mass, green leaf, stem, or dead fractions by endophyte status (Table 9). The grazed treatment with its two defoliations, compared to the stockpile, produced greatest DDM and CP per hectare from the tall fescue mass and from the green leaf and green stem fractions. The TNC produced was similar for the two defoliation treatments and attributed to the greater TNC concentrations in the stockpile but with less tall fescue mass. No difference was noted between defoliation treatments for the dead tissue.

Delaying the utilization of the stockpile from November to February did not alter the quantities produced of DDM, CP, and TNC from the tall fescue mass or from the green leaf component. The quantity of green-stem DDM showed a linear decline as did TNC. On the other hand, the DDM produced from the dead mass increased linearly as did the quantity of CP. This was associated with the decrease of green leaf (Table 5) and stem mass (Table 6) with a concomitant increase in dead mass (Table 7) as utilization of the stockpile was delayed into the winter.

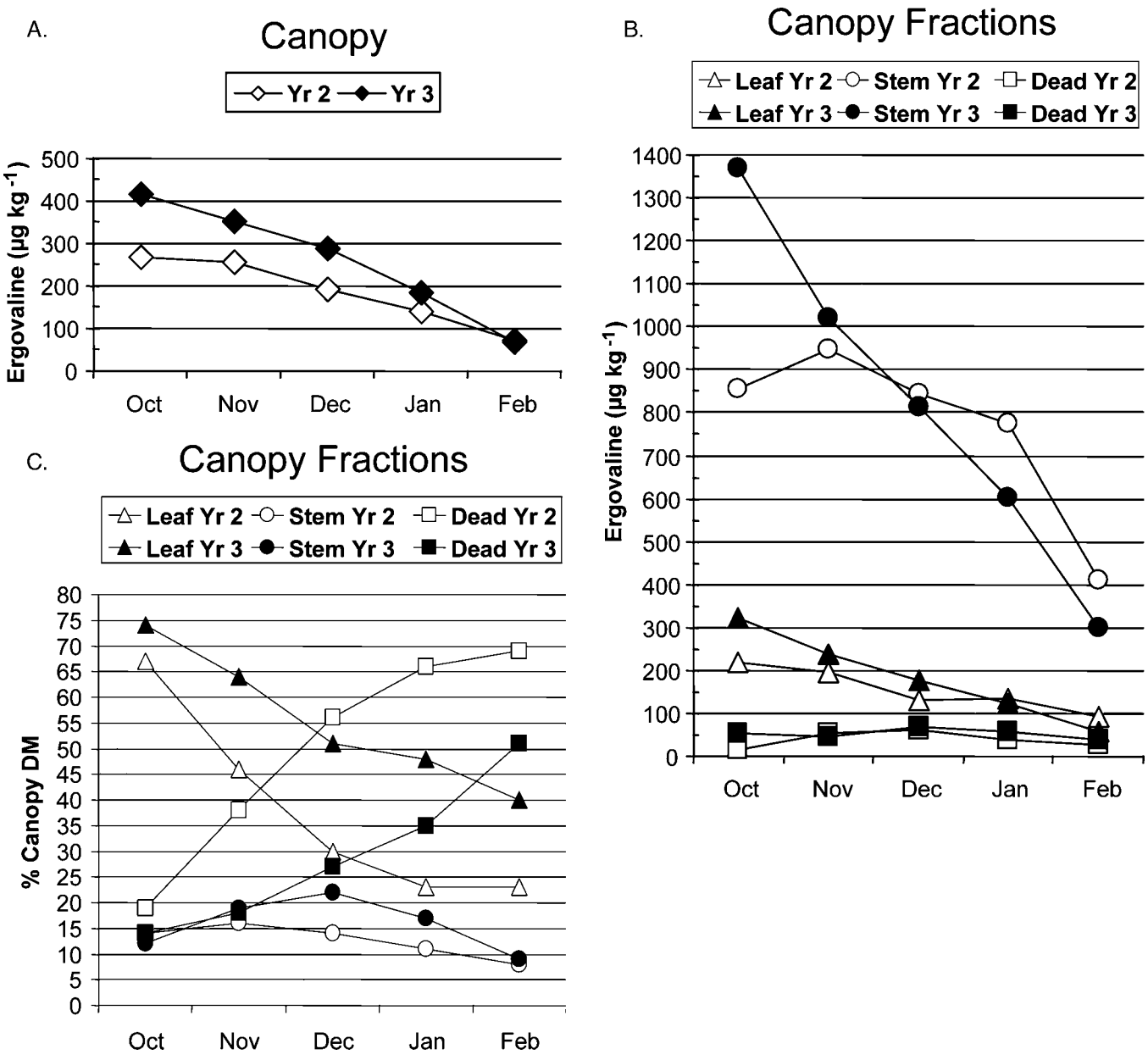

Fig. 2. (A) Year differences (Years 2 and 3) in ergovaline concentrations (near-infrared reflectance [NIR] predicted) of the grazed (October defoliation only) and stockpiled Jesup with the wild-type endophyte for the canopy, (B) the associated ergovaline concentrations, and (C) proportions of the tall fescue in leaf, stem, and dead fractions (mean of three replicates).

From both a nutritive value and utilization standpoint, the source of nutrients in stockpiled tall fescue present in either leaf or stem, or both, compared with that present in dead tissue is of major importance (Burns and Chamblee, 2000). The greatest proportion of the nutrients, and hence nutritive value of stockpiled tall fescue, occurred in the green leaf and green stem, however, the greatest concentration of ergovaline, an antiquality constituents, also occurred in the same tissue but with stem concentrations greatest. Delayed grazing of the stockpile resulted in a decrease of green leaf and green stem tissue which also reduces ergovaline concentration of the tall fescue mass as well as beneficial nutrients. Further, the concomitant increase in dead mass has a high potential, if consumed, to reduce animal performance. However, grazing animals selectively consume green tissue and avoid dead tissue when given the opportunity (Hodgson et al., 1994). This behavior permits grazing animals to consume a diet greater in nutritive value than represented by the available forage mass. However, the ergovaline concentration of the stockpile green leaf is only a fraction of that found in the green stem and the green stem proportion is only a fraction of the green leaf mass resulting in greatly reduced consumption of ergovaline. Dead plant tissue in the tall fescue canopy may simply represent dry matter lost for potential utilization. Also, dead tissue is rather quickly incorporated into the litter on the soil surface making it less available for grazing or harvest. Consequently, delaying tall fescue utilization beyond mid-December appreciably decreases ergovaline and nutritive

Table 9. Nutrients† produced from tall fescue and component green leaf, green stem, and dead fraction without and with wild-type and MaxQ endophytes when grazed or stockpiled until mid-February (dry matter basis).

Item	Whole plant			Green leaf			Green stem			Dead		
	DDM	CP	TNC	DDM	CP	TNC	DDM	CP	TNC	DDM	CP	TNC
	kg ha^{-1}											
Endophyte‡												
Wild type	3100	540	740	1650	330	470	490	50	220	960	160	40
MaxQ	3230	580	760	1730	350	490	510	60	230	990	170	40
Free (F)	3040	530	700	1570	310	450	460	50	200	1000	160	50
Significant (*P*)	0.83	0.70	0.65	0.59	0.60	0.38	0.85	0.82	0.80	0.93	0.77	0.29
Defoliation												
Grazed (G)§	4530	990	930	3000	730	660	700	90	240	820	170	30
Stockpile (S)¶	2770	440	680	1310	230	420	430	40	210	1030	170	50
November	3060	480	870	1760	310	560	560	50	290	740	120	30
December	2720	430	740	1360	240	460	470	50	240	900	150	40
January	2930	430	750	1220	190	450	460	50	220	1260	190	80
February	2360	410	370	925	180	240	240	30	90	1200	210	40
Significance (*P*)												
G vs. S	<0.01	<0.01	0.24	<0.01	<0.01	0.13	<0.01	<0.01	0.47	0.08	0.89	0.26
S Trend#												
L	0.38	0.62	0.09	0.16	0.24	0.12	0.02	0.12	<0.01	<0.01	<0.01	0.38
Q	0.81	0.85	0.50	0.89	0.69	0.68	0.39	0.42	0.38	0.27	0.80	0.07
LOF	0.54	0.90	0.50	0.81	0.99	0.62	0.41	0.58	0.48	0.16	0.66	0.12

† DDM, digestible dry matter; CP, crude protein; TNC, total nonstructural carbohydrates.
‡ Each value is the mean of five defoliation treatments, 3 yr, and three replicates (n = 45).
§ Each value is the total of two defoliations and mean of three endophyte conditions, 3 yr, and three replicates (n = 27).
¶ Each value is the mean of four stockpile treatments, three endophyte conditions, 3 yr, and three replicates (n = 108).
# L, linear; Q, quadratic; LOF, lack of fit.

value but increases the loss of DDM (137%), CP (133%), and TNC (142%) for animal production.

Autumn Grazing

Repeated grazing of autumn growth is a management alternative and a potential complement to accumulating and utilizing a stockpile within a production system. In this management strategy, represented by the grazed treatment in this study, all three endophyte treatments were grazed each time canopy height reached 10 to 15 cm. Pastures were grazed in late September to early October and again in mid-October to mid-November (depending on the year). A third grazing was anticipated for this treatment, but no regrowth attained 10 cm after the second (mid-October to mid-November) defoliation. Generally, the grazed treatment had greater quantities of forage mass and the forage was of more favorable nutritive value relative to the stockpile treatments discussed previously. In the analyses of the data, no endophyte × grazing interaction was present so only the main effects are presented in tabular form.

Forage Mass and Nutritive Value

When grazed twice during the autumn when forage attained 10 to 15 cm, the presence of the wild-type or MaxQ endophytes did not alter forage mass produced, the quantity grazed, or its nutritive value (IVTD, CP, NDF, and TNC) (Table 10). The forage mass at each grazing was similar but steers removed less mass at the second grazing and this effect was also evident in the compressed canopy heights.

The IVTD of the tall fescue mass was similar between the two grazing periods. Both CP and NDF concentration were reduced in forage from the second grazing, whereas TNC concentration was much greater (185%). This increase in TNC probably diluted the CP and NDF concentration and maintained IVTD.

Tall Fescue Mass

Neither the proportion nor the nutritive value of the green leaf, green stem, or dead fractions of tall fescue was altered by the presence of the endophytes in the

Table 10. Forage mass, mass removed by grazing, reduction in compressed height, tall fescue (TF) mass, and nutritive value† without, and with wild-type and MaxQ endophytes when grazed in the autumn (dry matter basis).

Item	Forage mass			Compressed height			TF mass		Tall fescue			
	Total	Removed	Residue	Start	Ending	Reduction	TF	Other	IVTD	CP	NDF	TNC
Endophyte‡	kg ha^{-1}			cm		%	kg ha^{-1}		g kg^{-1}			
Wild type	2880	2350	520	10	6	33	2820	60	763	168	523	158
MaxQ	3250	2460	790	10	6	34	3230	20	767	171	518	158
Free	3120	2520	590	9	6	31	2790	330	777	171	519	162
Significance (*P*)	0.32	0.74	0.50	0.14	0.32	0.21	0.45	0.35	0.37	0.94	0.92	0.96
Grazings§												
1	3220	2770	450	11	7	36	3000	220	761	194	536	112
2	2940	2130	820	8	6	29	2890	50	777	147	503	207
Significance (*P*)	0.35	0.02	0.07	<0.01	<0.01	<0.01	0.73	0.23	0.16	<0.01	0.02	<0.01

† IVTD, in vitro true dry matter disappearance; CP, crude protein; NDF, neutral detergent fiber; TNC, total nonstructural carbohydrates.
‡ Each value is the mean of two grazings, 3 yr, and three replicates (n = 18).
§ Each value is the mean of three endophyte conditions, 3 yr, and three replicates (n = 27).

Table 11. Proportion of tall fescue that is green leaf, green stem, and dead and their nutritive value† without and with wild-type and MaxQ endophytes when grazed in autumn (dry matter basis).

	Green leaf					Green stem					Dead				
Item	Prop.‡	IVTD	CP	NDF	TNC	Prop.	IVTD	CP	NDF	TNC	Prop.	IVTD	CP	NDF	TNC
	%	g kg^{-1}				%	g kg^{-1}				%	g kg^{-1}			
Endophyte§															
Wild type	61	843	199	449	200	13	839	103	501	319	26	569	124	680	17
MaxQ	61	838	204	448	193	14	839	106	502	309	26	577	126	673	18
Free	61	845	204	452	187	16	839	107	507	303	23	579	128	690	17
Significance (*P*)	0.99	0.93	0.90	0.97	0.94	0.61	0.99	0.83	0.97	0.94	<0.01	0.61	0.93	0.30	0.96
Grazings¶															
1	66	817	228	487	117	14	813	119	557	226	20	561	136	681	14
2	56	867	177	413	270	14	865	92	450	395	30	590	116	681	21
Significance (*P*)	<0.01	<0.01	<0.01	<0.01	<0.01	0.85	<0.01	<0.01	0.08	<0.01	<0.01	<0.01	0.02	0.96	0.02

† IVTD, in vitro true dry matter disappearance; CP, crude protein; NDF, neutral detergent fiber; TNC, total nonstructural carbohydrates.
‡ Prop., proportion of dry matter.
§ Each value is the mean of two grazings, 3 yr, and three replicates (n = 18).
¶ Each value is the mean of three endophyte conditions, 3 yr, and three replicates (n = 27).

autumn-grazed forage (Table 11). The proportion of green leaf decreased in the forage at the second grazing with a concurrent increase in dead tissue. The proportion of green-stem tissue remained similar. On the other hand, the IVTD was greater in forage from the second grazing in all three plant fractions. The greater IVTD is attributed to the much greater TNC at the second grazing which averaged 2.3 times greater for green leaf, 1.8 times greater for green stem, and 1.5 times greater for the dead tissue. The large increase in TNC would have had a dilution effect on the concentration of the other constituents and is associated with the reduction in CP in all plant fractions and NDF in the leaf and stem fractions.

Digestible Dry Matter, Crude Protein, and Total Nonstructural Carbohydrates

Tall fescue mass, previously discussed (Table 9), and green leaf, green stem, and dead tissue mass, as well as the quantity of the nutrients produced, were not altered by endophyte status (Table 11). Each regrowth period produced similar green leaf, green stem, and dead tissue mass.

The quantities of DDM produced from the tall fescue mass, green leaf, and green stem mass were similar at the two grazing periods. The greater proportion of DDM produced from the second grazing as dead tissue is attributed to the increase in the proportion of dead tissue (Table 11). Similar quantities of CP were produced at each defoliation from the green stem and dead tissue mass but less CP was produced from green leaf tissue at the second grazing (Table 12). The quantities of TNC produced were greater at the second grazing from the tall fescue mass as well as from its green leaf, green stem, and dead fractions with quantity increasing by 1.6 to 2.6 times (Table 12).

Stand Persistence

Detailed stand counts at the time of the first year of forage accumulation showed stand indices to differ among endophyte status (P = 0.02), even though seeding rates and germination percentages were similar among seed lots (Table 13). The stand index for the wild type was greatest at 89.6% with the MaxQ index lower at 79.9%. The MaxQ stand index and endophyte-free index (70.6%) were similar but approached significance (P = 0.06). At the first evaluation, all stands were adequate and essentially weed free.

Four years after the initial scoring, stand counts again showed differences among endophyte status (P = 0.01). By this date, stand indices for MaxQ and wild type were similar; whereas, MaxQ had a greater stand index compared with the endophyte free. Reductions in the stand index occurred for all endophyte treatments (P = 0.03) being similar for MaxQ and the wild type (mean = 35.4%), but appreciably greater for the endophyte-free stands (75.3%). Some reduction in the stand index was expected with stand maturation due to the devel-

Table 12. Nutrients† produced in tall fescue and component green leaf, green stem, and dead fractions without and with wild-type and MaxQ endophytes when grazed in autumn (dry matter basis).

	Whole plant				Green leaf				Green stem				Dead			
Item	Mass	DDM	CP	TNC	Mass	DDM	CP	TNC	Mass	DDM	CP	TNC	Mass	DDM	CP	TNC
	kg ha^{-1}															
Endophyte‡																
Wild type	2820	2160	470	440	1710	1430	350	310	390	320	40	120	720	410	80	140
MaxQ	3230	2480	550	510	1980	1650	410	370	460	380	50	130	790	450	90	140
Free	2790	2160	470	440	1710	1430	350	310	410	340	40	120	670	380	80	120
Significant (*P*)	0.45	0.47	0.58	0.44	0.46	0.46	0.62	0.46	0.99	0.99	0.77	0.84	0.53	0.48	0.53	0.77
Grazings§																
1	3000	2260	560	330	1960	1590	440	220	420	340	50	100	610	330	80	70
2	2890	2270	430	600	1630	1420	290	430	420	360	40	150	840	490	90	190
Significance (*P*)	0.73	0.99	0.06	<0.01	0.06	0.17	<0.01	<0.01	0.99	0.99	0.54	0.04	0.08	0.04	0.25	<0.01

† DDM, digestible dry matter; CP, crude protein; TNC, total nonstructural carbohydrates.
‡ Each value is the mean of two grazings, 3 yr, and three replicates (n = 18).
§ Each value is the mean of three endophyte conditions, 3 yr, and three replicates (n = 27).

Table 13. Tall fescue stands and the proportion of weeds present in the forage mass dry matter without and with wild-type and MaxQ endophytes when grazed or stockpiled until mid-February.

Item	Tall fescue stand index†			Weeds‡		
	Before	After	Reduction	Yr 1	Yr 2	Yr 3
	%					
Endophyte§						
Wild type (W)	90	64	29	0.0	<1	5
MaxQ (MQ)	80	47	42	0.0	<1	3
Free (F)	71	18	75	0.0	1	11
Significance (*P*)	0.02	0.01	0.03	–	0.46	0.13
MQ vs. W	0.05	0.15	0.37		0.98	0.50
MQ vs. F	0.06	0.03	0.04		0.29	0.05
Defoliation						
Grazed (G)¶	86	49	44		1.4	12
Stockpile (S)#	79	41	50		0.3	5
November	79	44	47		0.9	9
December	79	37	55		0.1	10
January	81	40	52		0.0	0.0
February	76	43	45		0.0	1
Significance						
G vs. S	<0.01	0.07	0.29		0.13	<0.01
S trend††						
L	0.39	0.84	0.64		0.33	<0.01
Q	0.27	0.19	0.11		0.56	0.98
LOF	0.37	0.48	0.79		0.87	0.03

† Stand index expressed as a percentage of 25-mm sections in 1-m transect containing fescue.
‡ Weeds = broadleaf and weedy grasses as a percentage of forage mass dry matter.
§ Each value is the mean of five defoliation treatments, 3 yr, and three replicates (n = 45).
¶ Each value is the mean of three endophyte condition, 3 yr, and three replicates (n = 27).
# Each value is the mean of four stockpile treatments, three endophyte conditions, 3 yr, and three replicates (n = 108).
†† L, linear; Q, quadratic; LOF, lack of fit.

opment and competition from seedlings that either emerged early after seeding or were more aggressive in their development, or both. The difference in stand-index reduction between MaxQ and endophyte free ($P = 0.04$) is of concern and consistent with the literature (Hill et al., 2002). The reduction in the endophyte-free stand index was significant, and the occurrence of weeds evident as the study progressed attaining significance ($P = 0.05$) in the fourth year after establishment (Table 13).

As noted for the endophyte status, the stand indices were greatest for the grazed vs. the stockpile plots. After 3 yr of defoliation (4 yr after establishment) stand indices were similar between defoliation treatments as was stand reduction, but the weed percentage was greatest in the grazed treatment.

The reduction in the tall fescue–stand index during the 3-yr study was not altered by the length of the stockpile treatment. In year 3, delaying grazing of the stockpile reduced the percentage of weeds linearly (Table 13). The significant lack of fit term reflects the shifts from December to February. This decline was attributed mainly to repeated frost which killed the weedy grasses (mainly warm season annuals) and broad-leafed weeds causing them to collapse and fall below the sampling height.

CONCLUSIONS

Excellent stands of Jesup tall fescue were easily established and were readily grazed by steers. The presence of the novel endophyte in the MaxQ grazed forage or the accumulated stockpile gave results comparable to the endophyte-free in forage mass, changes in green leaf, stem, and dead tissue proportions, and in each of their mass, and in nutritive value and ergovaline of tall fescue mass and of the leaf and stem tissues. It is also noted that MaxQ was not different from the wild type for these same measurements with the exception of ergovaline. MaxQ gave tall fescue stand indices that did not differ from the wild-type endophyte, but were superior to Jesup that was endophyte-free (Hill et al., 2002). The latter had reduced plant stand indices that reflected a reduction in tall fescue and an increase in weedy species by the end of the third year. Autumn grazing of tall fescue, compared with stockpiling, generally resulted in greater forage mass, greater nutritive value of the forage, greater green leaf and green stem mass, and less dead-tissue mass but regrowth adequate for grazing ceased by mid-November. In the case of the stockpile, delaying utilization until mid-February reduced forage and tall fescue mass and nutritive value (Balasko, 1977; Rayburn et al., 1979; Collins and Balasko, 1981; Burns and Chamblee, 2000) as well as ergovaline concentrations (Kallenbach et al., 2003). Reduced nutritive value was attributed to a large decrease in green leaf tissue (of greatest nutritive value) and a concomitant increase in dead tissue (least nutritive value). The reduction in ergovaline, greatest in green stem which composed the least and a declining fraction of the stockpile, and least in dead tissue, which composed the greatest and an increasing fraction of the stockpile, can reduce the concern of the toxin when grazing stockpiled tall fescue. A management strategy that favors the retention of green leaf prior to utilization will be reflected in the nutritive value of the stockpile. Jesup tall fescue with novel (nontoxic) endophyte and marketed as MaxQ has the potential in animal grazing systems to provide tall fescue mass and nutritive value during the autumn and winter comparable to the wild-type or endophyte-free. Furthermore, this is achieved while maintaining pasture stand density comparable to the wild-type and superior to the endophyte-free without the risks of toxicosis associated with ergovaline. Producers that are utilizing tall fescue that produce ergovaline, however, can reduce the potential of toxicosis by delaying grazing as late in the winter as possible.

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REFERENCES

AOAC. 1990. Official methods of analysis, 15th ed. Assoc. of Official Analytical Chemists, Arlington, VA.

Archer, K.A., and A.M. Decker. 1977. Autumn-accumulated tall fescue and orchardgrass. II. Effects of leaf death on fiber components and quality parameters. Agron. J. 69:605–609.

Balasko, J.A. 1977. Effects of N, P and K fertilization on yield and quality of tall fescue forage in winter. Agron. J. 69:425–428.

Bouton, J.H., R.R. Duncan, R.N. Gates, C.S. Hoveland, and D.T. Wood. 1997. Registration of 'Jesup' tall fescue. Crop Sci. 37:1011–1102.

Bouton, J.H., G.C.M. Latch, N.S. Hill, C.S. Hoveland, M.A. McCann, R.H. Watson, J.A. Parish, L.L. Hawkins, and F.N. Thompson. 2002. Reinfection of tall fescue cultivars with non-ergot alkaloid producing endophytes. Agron. J. 94:567–574.

Buckner, R.C., J.B. Powell, and R.V. Frakes. 1979. Historical development. p. 1–8. *In* R.C. Buckner and L.P. Bush (ed.) Tall fescue. Agron. Monogr. 20. ASA, CSSA, and SSSA, Madison, WI.

Burns, J.C., and D.S. Chamblee. 1979. Adaptation. p. 9–30. *In* R.C. Buckner and L.P. Bush (ed.) Tall fescue. Agron. Monogr. 20. ASA, CSSA and SSSA, Madison WI.

Burns, J.C., and D.S. Chamblee. 2000. Summer accumulation of tall fescue at low elevations in the Piedmont: II. Fall and winter changes in nutritive value. Agron. J. 92:217–224.

Burns, J.C., and W.A. Cope. 1974. Nutritive value of crownvetch forage as influenced by structural constituents and phenolic and tannin compounds. Agron. J. 66:195–200.

Collins, M., and J.A. Balasko. 1981. Effects of N fertilization and cutting schedule on stockpiled tall fescue: II. Forage quality. Agron. J. 73:821–826.

Cowan, J.R. 1956. Tall fescue. Adv. Agron. 8:283–320.

Duell, R.W. 1960. Utilization of fertilizer by six pasture grasses. Agron. J. 52:277–279.

Fribourg, H.A., and K.W. Bell. 1984. Yield and composition of tall fescue stockpiled for different periods. Agron. J. 76:929–934.

Funk, C.R., P.M. Halisky, S. Ahmad, and R.H. Hurley. 1985. How endophyte modify turfgrass performance and response to insect pests in turfgrass breeding and evaluation trials. p. 137–145. *In* F.L. Lemaire (ed.) Proc. 5th Int. Turf Res. Conf., Avignon, France. 1–4 July 1985. INRA, Versailles, France.

Hill, N.S., J.H. Bouton, F.N. Thompson, L. Hawkins, C.S. Hoveland, and M.A. McCann. 2002. Performance of tall fescue germplasms bred for high-and-low ergot alkaloids. Crop Sci. 42:518–522.

Hill, N.S., G.E. Rottinghaus, C.S. Agee, and L.M. Schultz. 1993. Simplified sample preparation for HPLC analysis of ergovaline in tall fescue. Crop Sci. 33:331–333.

Hill, N.S., F.N. Thompson, D.L. Dawe, and J.A. Stuedemann. 1994. Antibody binding of circulating ergopeptine alkaloids in cattle grazing tall fescue. Am. J. Vet. Res. 55:419–424.

Hodgson, J., D.A. Clark, and R.J. Mitchell. 1994. Foraging behavior in grazing animals and its impact on plant communities. p. 796–827. *In* G.C. Fahey, Jr. (ed.) Forage quality, evaluation and utilization. ASA, CSSA, and SSSA, Madison, WI.

Kallenbach, R.L., G.J. Bishop-Hurley, M.D. Massie, G.E. Rottinghaus, and C.P. West. 2003. Herbage mass, nutritive value, and ergovaline concentration of stockpiled tall fescue. Crop Sci. 43:1001–1005.

Marten, G.C., and A.W. Hovin. 1980. Harvest schedule, persistence, yield and quality interactions among four perennial grasses. Agron. J. 72:378–387.

Ocumpaugh, W.R., and A.G. Matches. 1977. Autumn-winter yield and quality of tall fescue. Agron. J. 69:639–643.

Oliver, J.W. 1997. Physiological manifestations of endophyte toxicosis in ruminant and laboratory species. p. 311–346. *In* C.W. Bacon and N.S. Hill (ed.) *Neotyphodium*/grass interactions. Plenum Press, New York.

Parish, J.A., M.A. McCann, R.H. Watson, N.N. Paiva, C.S. Hoveland, A.H. Parks, B.L. Upchurch, N.S. Hill, and J.H. Bouton. 2003. Use of nonergot alkaloid-producing endophytes for alleviating tall fescue toxicosis in stocker cattle. J. Anim. Sci. 81:2856–2868.

Prigge, E.C., W.B. Bryan, and E.S. Goldman-Innis. 1999. Early-and late-season grazing of orchardgrass and fescue hays overseeded with red clovers. Agron. J. 91:690–696.

Randall-Schadel, B. 1995. Tall fescue endophyte analysis. p. 129. *In* D.S. Chamblee and J.T. Green (ed.) Production and utilization of pastures and forages in North Carolina. Tech. Bull. 305. North Carolina Agric. Res. Serv., Raleigh, NC.

Rayburn, E.B., R.E. Blaser, and D.D. Wolf. 1979. Winter tall fescue yield and quality with different accumulation periods and N rates. Agron. J. 71:959–963.

Roberts, C.A., R.E. Joost, and G.E. Rottinghaus. 1997. Quantification of ergovaline in tall fescue by near infrared reflectance spectroscopy. Crop Sci. 37:281–284.

Ross, J.P., and J.H. Reynolds. 1979. Nutritive value of fall-stockpiled tall fescue. Tenn. Farm Home Sci. 112:44–48.

SAS Institute. 1995. SAS user's guide: Statistics. 5th ed. SAS Inst., Cary, NC.

Taylor, T.H., and W.C. Templeton, Jr. 1976. Stockpiling Kentucky bluegrass and tall fescue forage for winter pasturage. Agron. J. 68:235–239.

Templeton, W.C., Jr., G.O. Mott, and R.J. Bula. 1961. Some effects of temperature and light on growth and flowering of tall fescue, *Festuca arundinacea* Schreb. I. Vegetative development. Crop Sci. 1:216–219.

Thompson, F.N., J.A. Stuedemann, and N.S. Hill. 2001. Antiquality factors associated with alkaloids in eastern temperate pastures. J. Range Manage. 54:474–489.

Van Soest, R.J., and J.B. Robertson. 1980. Systems of analysis for evaluating fibrous feeds. p. 49–60. *In* W.J. Pigden et al. (ed.). Proc. Int. Workshop Standardization of Anal. Methodol. for Feeds. Int. Devel. Res. Cent., Ottawa, ON. 12–14 Mar. 1979. Unipub., New York.

West, C.P., E. Izekor, K.E. Turner, and A.A. Elms. 1993. Endophyte effects on growth and persistence of tall fescue along a water-supply gradient. Agron. J. 85:264–270.

Wolf, D.D. 1973. Report of research with forage crops. Dep. Agron. Virginia Polytech. Inst. State Univ., Blacksburg, VA.